International Journal of Research in Industrial Engineering

www.riejournal.com

Int. J. Res. Ind. Eng. Vol. 14, No. 1 (2025) 86–98.

Paper Type: Research Paper

A Decision-Making Method for Supplier Selection in Industrial Manufacturing Industry: A Mathematical Framework of Integrating Analytical Hierarchical Process and Reliability Risk Evaluation

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Citation:

Received: 20 August 2024 *Revised: 25 October 2024* *Accepted: 13 November 2024*	Sheel, C., Rahman, S., & Bhowmick, T. (2025). A decision-making method for supplier selection in industrial manufacturing industry: A mathematical framework of integrating analytical hierarchical process and reliability risk evaluation in the field of industrial engineering sectors. *International journal of research in industrial engineering, 14*(1), 86-98.

Abstract

The supplier is a crucial component of the supply chain, with the supply chain encompassing vendor management. Selecting an industry-appropriate supplier involves assessing the supplier's performance. This selection process not only satisfies customer requirements and generates profit for the organization but also ensures compliance with all defined supplier attributes. The task of choosing an appropriate supplier is essential and can often be challenging. The objectives of the supply chain include enhancing productivity, reducing costs, and meeting the demands of emerging markets. This thesis introduces the concept of relative reliability risk assessment, particularly for new suppliers. Measuring performance is critical for vendor selection, as failure to do so can negatively impact the organization's reputation. The paper employs a four-tier method: establishing a functional structure, applying the Analytical Hierarchical Process (AHP), utilizing the entropy method, and organizing alternative functionality graphs. The model's effectiveness is demonstrated through empirical case studies and comparisons with traditional supplier selection methods, showcasing its capability to manage uncertainty and improve decision accuracy.Multiple alternatives and criteria are considered to facilitate the decision-making process for selecting suitable vendors. The AHP is utilized for multi-attribute decision-making among various vendors, effectively addressing the inherent biases, vagueness, and subjectivity in human decision-making. The Eigenvalue of the AHP is calculated in Excel using specific formulas, with the consistency index being determined each time. The entropy method is applied to calculate the weights of different attributes, which are then used to compute the Relative Reliability Risk Index. The alternative functionality graph displays the strengths and weaknesses of all alternatives concerning multiple attributes. A real-life case study demonstrating the application of Multiple Attribute Decision Making (MADM) with the proposed method is presented in this paper. The suggested model offers valuable insights for practitioners aiming to enhance supplier selection strategies and boost overall supply chain performance.

Keywords: Reliability, Analytical hierarchical process, Relative reliability risk index, Alternative functionality graphs, Multiple attribute.

1 | Introduction

A diverse range of specialty papers encompasses tissue paper, rice paper, label paper, laid paper, greaseproof paper, rust paper, currency paper, thermal paper, tracing paper, filter paper, teabag paper, aluminum foil

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https://doi.org/10.22105/riej.2024.474342.1469

paper, carbon paper, carbonless paper, wallpaper, and other types [1]. Moreover, the specialty papers comprise of such papers glassine papers, battery separator papers, cash-infused paper, cigarette papers and related group of paper categories [1]. Given the depletion of natural resources and the imperative of ensuring profitability, the significance of Green Supply Chain Management (GSCM) has markedly increased in the context of contemporary globalized efforts aimed at environmental preservation [2]. The goal of producing more environmentally friendly products with less than usual inputs and more focusing on quality and human health can be obtained through GSCM. GSCM is one of the many methods of environmental protection [2]. In accordance with Bozdağ et al. [3], supplier selection criteria generally belong to four main categories: supplier coverage, product performance, service performance, and cost criteria. Service performance criteria assess the advantages offered by the supplier's services and encompass various aspects: subsequently match of feedback, improvement of technical support, economy of time and dedication towards professionalism will set apart the company [4], [5]. In the realm of software services, as outlined by Chin and Ahmed (2014), the selection process for a Software Provider (SP) comprises two distinct parts of selection criteria: the enterprise criteria and SP criteria. The enterprise criteria are intricately linked with the product quality specifications of the new software intended for adoption by the company [4].

The main aim of the process of supplier selection is to determine the supplier which meets the requirements and rules of the company's specific decision criteria [6]. The manufacturing company audit every supplier's ability to meet its need successfully [6]. The challenge lies in translating qualitative specifications into quantifiable criteria for effective evaluation [6]. Supplier selection represents a multi-criteria decision-making (MCDM) challenge that holds strategic significance for enhancing the competitiveness of high-tech manufacturing firms [4]. However, empirical evidence demonstrating the practical efficacy of MCDM methodologies, particularly in the context of evaluating service quality, remains limited [4].

This paper aims to address this issue by employing a fuzzy-based Analytic Hierarchy Process (fuzzy-AHP) approach [6].The decision-making process for selecting a vendor is complex and critical. Choosing an inappropriate vendor can have direct implications on the company's production processes and operational costs [1]. The first goal of this paper is to identify and classify several principles that would form supplier selection criteria for the case study company. Then a flexible analytic model which is AHP will have to be utilized to support the case company in the selection of the best supplier for JIT Procurement implementation [1].

Consequently, the research seeks to close this gap in the literature to ensure that the study adequately addresses fundamental inquiries concerning technology sustainability, necessitating enhanced handling of imprecision [2].

The necessitate the formulation of precise targets and metrics in readiness for implementation, thereby facilitating increased and regular information exchange with suppliers [1]. Earlier supplier's involvement determines whether the JIT procurement will work or not .Moreover supplier certificates can be supporting evidence for their environmental consciousness [1]. Streamlining of the transaction process may lead to the reduction in operation cost, better marketing competitiveness and maximized profits as well [1].

More recent investigation and application of the AHP with the fuzzy-based expansions and corrections to address practical issues in the areas selector of software and more widely generalized suppliers have demonstrated high level of success [7]. With reference to the issue of computer aided design systems evaluation, Bozdağ et al. [3] used the fuzzy-AHP tool to compare four groups of methods namely; sensing, visualization, real-in-motion, and computer-integrated manufacturing systems. Shamsuzzaman et al. [8] proposed a hybrid model which has both fuzzy sets and analytical hierarchy process in order to measure rankings of the best manufacturing system [7].

Primarily, target selection assumes paramount importance in this endeavor, as it entails identifying critical criteria for selecting a specific product category [7]. The role of manufacturing management is fulfilled through a systematic review of scholarly literature on supplier selection issues and through the competence

of experts in the industrial domain [7]. When the screening criteria have been already determined, the next step is to score the criteria according to the Saaty scale [9]. These items in turn help to rank the criteria against the AHP criteria [7].

The experience of such data is acquired through interview and then the collected data is systematized by applying questionnaires [1]. During the empirical part of the research data collection and calculations, results and discussion will follow and it will be recommended that most appropriate supplier for the selected business would be chosen and guidelines for maintaining the relationship with the selected vendor [1].

Phase 1: thesis background, research problems, methodology and the thesis objectives.

Phase 2: literature review of purchasing behavior, supplier related theory and AHP method.

Phase 3: qualitative method of interview and quantitative research method of questionnaires.

Phase 4: data collection and calculation, results and discussion.

Phase 5: thesis summary and limitation analysis.

2 | Materials and Methods

The Analytic Hierarchy Process (AHP) is a widely used Multi-Criteria Decision Making (MCDM) approach for determining the relative weights of criteria. In the AHP method, the problem structure is typically represented as a multilevel. The overarching objective is to resolve the issue at hand hierarchy [10]. Situated within the intermediate layers are the tactical steps required for this purpose. The foundation layer delineates the criteria and sub-criteria essential for problem-solving [10]. Pairwise evaluations are methodically conducted to generate matrices encompassing all possible combinations of criteria and sub-criteria at the designated level [10]. AHP facilitates finding solutions that are the best fit to the problem and goal of the decision maker. It provides a quite efficient, logical, and uniform approach for structuring a decision problem, for representing and quantifying its elements, for connecting the elements with the goals, and for assessing the solutions [7].

The AHP technique can be described in the following steps:

Step 1. Constructing the fuzzy comparison matrices of the criteria regarding the set objective so that we can employ the questionnaire form to gather the data.

Step 2. Identifying the synthetic fuzzy extent value of every criterion.

Step 3. Finding the according possibility of kinds of fuzzy that may have different approaches towards utilitarian values.

Step 4. Defining the lowest level which is the current possibility of success in the case of all the methods criterion over another.

Step 5. Managers can determine the effectiveness of each criterion using the minimum weights.

Step 6. Standardizing the criteria, normalizing the individual vertex weights, and determining the final weight of criteria used for the purpose of making decisions with the goal in mind.

Step 7. Doing the same for all the next sub criteria to find the final weight for each sub criteria respectively. They are considered based on their qualifications.

Step 8. In addition to this, sorting the decision priorities in relation to the chosen option of sub-attributes.

Step 9. Obtaining the importance scores multiply the priority weights of the decision alternatives with them, the next step is to establish the decision matrix and listing sub-criteria and evaluate the importances of options in terms of the main criteria.

Step 10. Generation of priority weights of decision alternatives by use of multiplying the priority and sorting criteria for the final decision to retrieve the best alternatives out of them to the primary goal.

Step 11. The global supplier that is the best performer is going to be selected according to the highest weight priority [6].

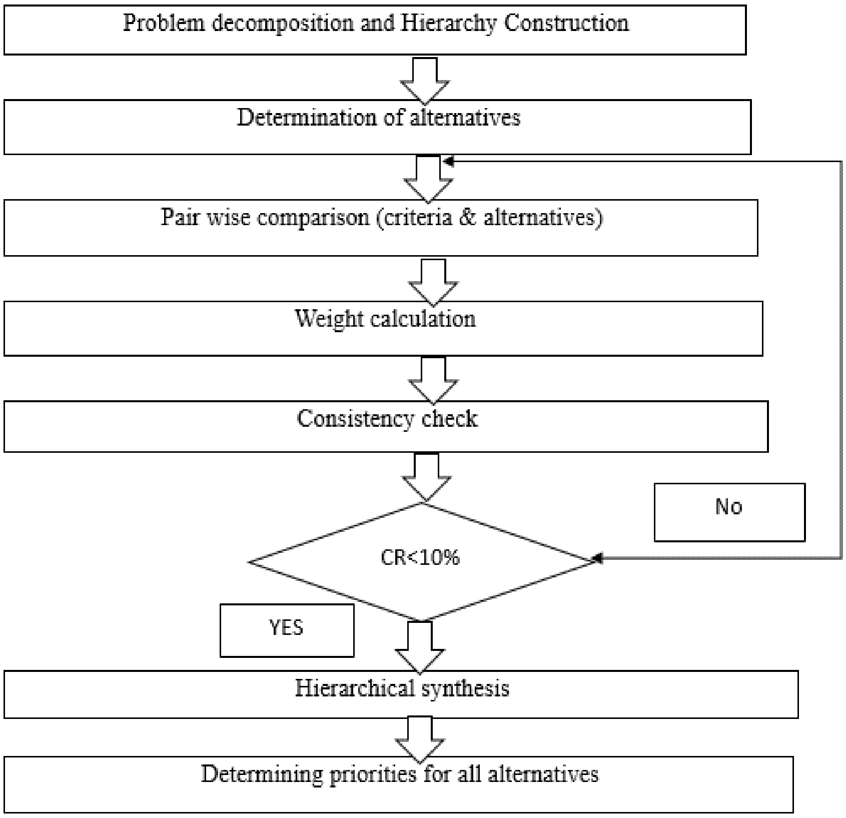

Fig. 1. Schematic representation of the methodology.

The primary problem is disintegrated into a collection of easily understandable smaller subproblems. Each subproblem is analyzed independently. The hierarchy consists of the decision goal and the criteria of its assessment. Defined in the *Table 1* is Saaty scale [9] that will be used for AHP [7]. The AHP methodology is elucidated using the following equations:

Table 1. Saaty scale used in AHP [7], [9].

Intensity of Importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective
3	Somewhat more important	Experience and judgment slightly favor one over the other
5	Much more important	Experience and judgment strongly favor one over the other
7	Very much more important	Experience and judgment very strongly favor one over the other
9	Extremely more important	The evidence favoring one over the other is of the highest possible affirmation
2,4,6,8	Intermediate scores	

According to Robert [11], a crucial aspect of supplier selection involves establishing criteria. Five key components that should be considered during the supplier selection process: cost, quality, time, reliability, technology [1].

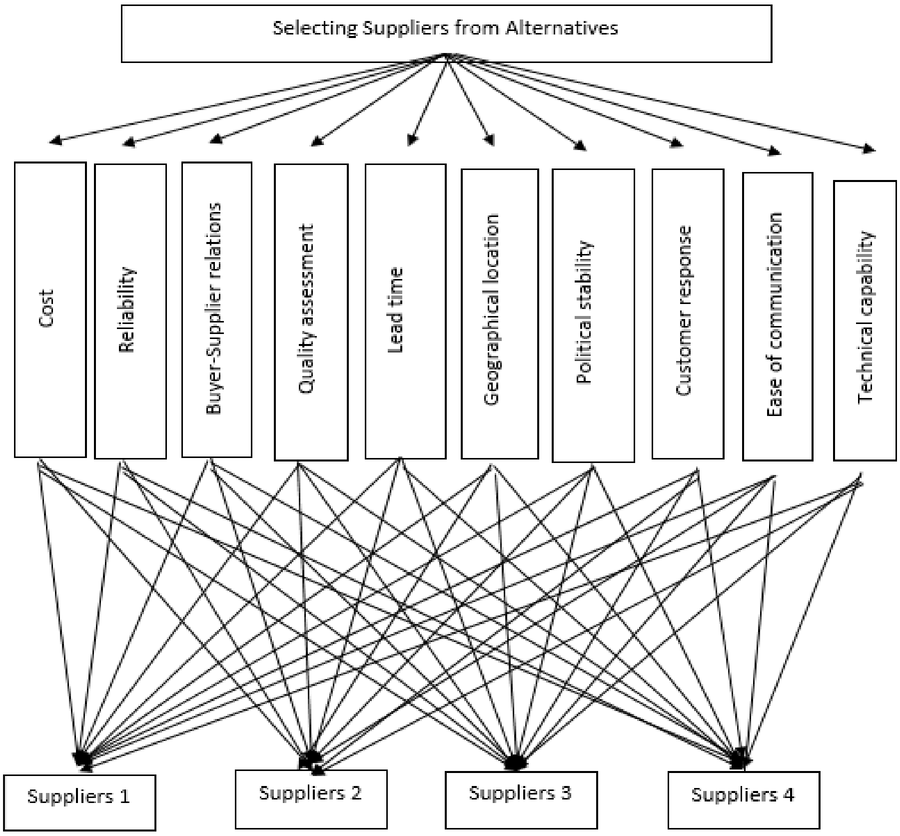

Fig. 2. Schematic representation aboyt the relationship between supplier and constraints.

Within manufacturing companies, the cost of raw materials is a fundamental component of expenses, directly influencing the overall product cost and, consequently, impacting product pricing, sales volume, and ultimately, corporate profitability [1]. Manufacturing enterprises actively seek opportunities for collaboration with suppliers due to the critical impact of raw material quality on the final product's quality. This, in turn, influences the product's pricing and marketing sales volume [1]. Reliability pertains to a supplier's capacity to uphold commitments, demonstrate honesty towards buyers, maintain a strong reputation within the industry, and collaborate effectively with other highly reliable suppliers, thereby offering a more assured guarantee of success [1]. The punctuality of delivery holds greater significance than pricing indicators in JIT Procurement. This is because JIT Procurement is characterized by minimal or zero inventory to reduce business costs, necessitating uninterrupted production processes [1]. The level of information sharing pertains to the capacity for exchanging information between the buyer and supplier [1]. The supply capability indicator is employed to assess whether a vendor possesses the capacity to consistently meet the requirements of a manufacturing company at any given time. This indicator forms the foundation for suppliers to maintain punctual delivery schedules [1].

The matrix will undergo specific mathematical procedures to determine its eigenvectors and eigenvalues.

Eigenvector Ei.

First, to multiply all values in the row:

$$M_i = a_{i1} + \cdots a_{ij} = \sum_i^n a_{ij} \qquad (i, j = 1 \ldots n, n = 6),$$

$$W = \sqrt[n]{M_1} + \cdots \sqrt[n]{M_i} = \sum_i^n \sqrt[n]{M_i} \quad (i, j = 1 \ldots . n, n = 6),$$

$$E_i = \sqrt[n]{M_i / W (i, j = 1 \ldots n, n = 6)}.$$

After computing the eigenvectors and eigenvalues, the subsequent step involves verifying the consistency of the judgment matrix. This verification ensures that the judgment matrix adheres to logical reasoning. Only if the matrix passes the consistency test can we proceed to estimate the weights of the indicators using the eigenvectors and eigenvalues. This analysis is meaningful for obtaining the final results based on the existing data:

Firstly, need to calculate Consistency Index C.I.

C.I. = $\lambda max - n / n - 1$.

Secondly, to ascertain the appropriate average Random consistency Index (R.I.), refer to the table provided below:

Table 2. Corresponding average R.I. [9].

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

Next, the Consistency Ratio (C.R.) is calculated to evaluate whether the judgment matrix meets the consistency requirement.

C.R. = C. I/R.I.

If the C.R. falls below 0.1, the judgment matrix fulfills the consistency criterion. Conversely, if the C.R. exceeds 0.1, the judgment matrix fails to meet the consistency standard, necessitating adjustments to be made accordingly.

The determination of the relative significance of supplier selection criteria was accomplished through the AHP calculation method, which was applied to assign solution factors to Layer B .Additionally, the judgment matrices remain to be computed and subjected to consistency testing using the aforementioned calculation procedure [1].

The eigenvectors and eigenvalues obtained from both the criteria layer and the solution layer demonstrate logical validity. These vectors and values have been organized to facilitate the calculation of the final result .By performing matrix multiplication, one's can determine the relative rates for the suppliers, aiding in the selection of the most suitable alternative [1].

3 | Calculations and Result

Here A, B, C, D denote vendors name.

A= Altex Fabrics Ltd.

B= Beximco padma textiles.

C= Amex knitting and dying Ltd.

D= Artistic collection.

CM= Consistency measure.

RI=Random index.

CR=Critical Ratio.

Table 3. Cost criteria used for calculating eigenvalue.

Cost	A	B	C	D			
A	1.00	5.00	3.00	0.33			
B	0.20	1.00	0.25	0.20			
C	0.33	4.00	1.00	0.33			
D	3.00	5.00	3.00	1.00			
Total	4.54	15.00	7.25	1.87			
Cost	**A**	**B**	**C**	**D**	**Total**	**Average**	**C M**
A	0.22	0.33	0.41	0.18	1.15	0.29	4.39
B	0.04	0.07	0.03	0.11	0.25	0.06	4.10
C	0.07	0.27	0.14	0.18	0.66	0.16	4.11
D	0.66	0.33	0.41	0.54	1.95	0.49	4.43
						CI=	0.09
						RI=	0.90
						C. Ratio=	0.09

After the application of AHP, using *Table 3*, the priority matrix obtained is shown in *Table 4* below. This will be treated as our decision matrix.

Main Vendor i = 1 to n →

Functions

j = 1 to

Table 4. Decision matrix.

K	A	B	C	D
Cost	0.29	0.06	0.16	0.49
Reliability	0.60	0.07	0.10	0.23
Buyer-supplier relationship	0.51	0.13	0.26	0.10
Quality assessment	0.56	0.10	0.23	0.11
Lead time	0.33	0.21	0.12	0.34
Political stability	0.14	0.48	0.26	0.13
Geographical location	0.47	0.10	0.22	0.21
Customer response	0.55	0.16	0.16	0.13
Technical capability	0.58	0.21	0.13	0.09
Ease of communication	0.65	0.14	0.12	0.09

The weights for the four functions considered have been calculated using the information from the decision matrix and the entropy method. The entropy method is Multi-Attribute Decision Making method, as stated by Hwang [12]. This method has been adopted as a part of calculating R3 I, because it may be inappropriate for a decision maker to compare functions relatively from the function structure. The information contents of the normalized values of the attributes can be measured using entropy values. The entropy Vj of the set of normalized outcomes of attribute j is given below.

Table 5. Table for calculating weight factor.

$$V_j = -\beta \sum_{i=1}^{n} (l_{ij} * \ln (l_{ij})) \quad \text{for all } j\ (j = 1 \text{ to } k \text{ represents attributes})\ \&\ (i=1 \text{ to } N \text{ represents alternatives})$$

β = constant = 1 / ln (n); l_{ij} = Normalized element of the decision matrix

If there are no preferences available, the weights are calculated using the equation,

$$W_j = E_j / \left(\sum_{j=1}^{k} E_j\right) \text{ and}$$

$$E_j = \quad - V_j$$

If the decision maker has the weights available beforehand i.e. We, then it can be combined with the weights calculated above, resulting in new weights that are Wnew

$$W_{new} = (W_e * W_j) / \left(\sum^{k} W_e * W_j\right)$$

The weights for the four functions considered have been calculated using the information from the matrix and the entropy method is utilized to calculate the same. The weights obtained after the application of the method are shown in *Table 6*. Normalization of the decision matrix is not required.

Table 6. Relative reliability risk calculation.

$$R^3 I_i = \sum_{j=1}^{k} (l_{ij} * W_j), \quad \text{for all } i$$

Table 7. Weights for the attributes.

Sl.No	Criteria	Weights
1	Cost	0.092
2	Reliability	0.144
3	Buyer-supplier relationship	0.084
4	Quality assessment	0.108
5	Lead time	0.030
6	Political stability	0.061
7	Geographical location	0.062
8	Customer response	0.099
9	Technical capability	0.160
10	Ease of communication	0.160

Sample Calculations

β = constant = 1 / ln (n); n = No. of the alternatives.

β = constant = 1 / ln (4).

β = 1/ (1.386).

β = 0 .72135.

N.

$V_j = -\beta \sum (l_{ij} * \ln (l_{ij})$, for all j (j = 1 to k represents attributes).

i = 1 & (i = 1 to N represents alternatives).

K.

$W_j = E_j / (\sum E_j)$.

j = 1.

K.

$$\sum Wj = (W1 + W2 + W33 + W4 + W5 + W6 + W7 + W8 + W9 + W10).$$
$$j = 1.$$
$$R3\,I\,i = \sum (l\,i\,j * W\,j), \qquad \text{for all i.}$$
$$j = 1.$$

Table 8. R^3 i and ranks for vendors–vendor selection.

Criteria	A	B	C	D
R3 I	0.519	0.152	0.165	0.174
Rank	1	4	3	2

It is seen that the over-all score for suppliers A is 0.519 is the largest value. Hence our selected supplier in AHP method is Suppliers A and then the Suppliers B, Suppliers C and Suppliers D.

AFGS are graphs between the functional priorities calculated by AHP and the alternatives. This approach to evaluating alternatives helps identify the strengths and weaknesses of all the alternatives, function-wise. Unfortunately, systematic methods are not always used in industries as stated by Chakraborty et al. [13]. Also, a huge vendor database comprising a large number of alternatives may produce a complex situation to recognize the strengths and weaknesses as regards to each function in the function structure as illustrated by [14]. AFGs are means to represent the strengths and weaknesses of alternatives after the comparison using AHP has been performed. The AFG for the above case study is shown below. X axis represents vendors A to F respectively. This figure is meant to depict a clear picture of the strengths and weaknesses of different vendor alternatives with respect to the functions.

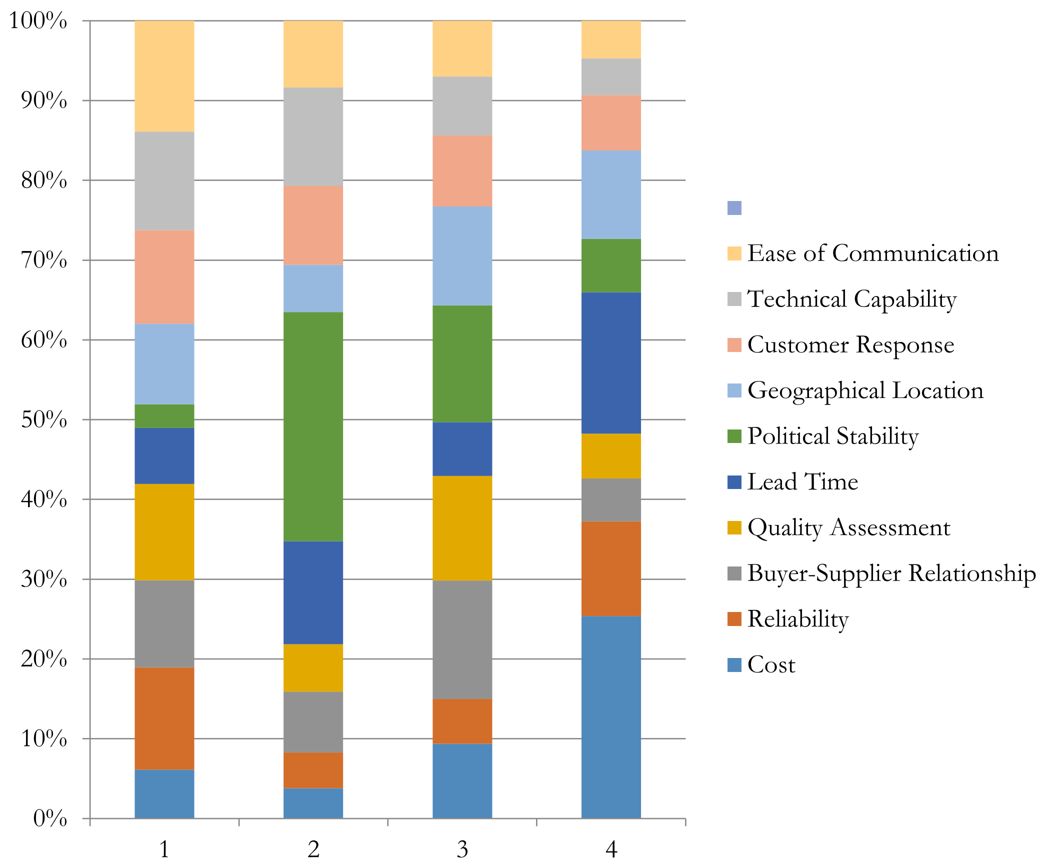

Fig. 3. Alternative functionality graphs.

4 | Conclusion

The criteria and solution layers exhibit eigenvectors and eigenvalues, which are consistent with logical reasoning. By integrating different factors and vectors in this study, it becomes clear that matrix multiplication is the most suitable method for matching the unspecified suppliers. Initially, it is essential to strategically limit the number of suppliers selected, potentially favoring a single-source supplier, to establish meaningful strategic alliances. During the initial stages of implementing JIT procurement within a specific company, directly transitioning from multiple suppliers to a single-source supplier can present significant challenges. Early stages of collaboration are susceptible to miscommunication, which can lead to risks such as untimely deliveries and potential disruptions in production. Consequently, a more prudent strategy would be to select two suppliers: one as the primary supplier and the other as a backup to mitigate these risks. Developing mutually beneficial business partnerships necessitates active communication, information exchange, mutual trust, and sustained long-term collaboration. These elements collectively form the foundation for establishing shared objectives and achieving mutual benefits in business relationships.

In supply chain management, the collaboration between manufacturers and suppliers represents a crucial and challenging aspect that significantly influences distribution channels [6]. Effective coordination and information sharing with suppliers play a pivotal role in determining the firm's performance [6]. The efficiency of suppliers holds paramount importance for the firm, as breakdowns in coordination can lead to significant delays and ultimately result in subpar customer service [6]. Fuzzy judgments, when used to evaluate alternatives, offer decision-makers several key advantages. First, they allow for practical and efficient comparison of alternatives based on evaluated sub-criteria. Second, they enable decision-makers to discern subtle nuances in people’s statements. Finally, fuzzy judgments facilitate the incorporation of information that may be imprecise, incomplete, unavailable, or only partially accessible, which is often encountered in real-world decision-making processes [4]. The mentioned three benefits are reflected in the obvious simplicity of the provided service evaluation strategy which is very simple in a computational sense and is finally based on a weighted average of markings [4]. Moreover, a traditional AHP technique has been utilized to address the company’s actual priorities and stated objectives in a structured manner comprehensively and accurately. This approach clarifies the specific requirements of the software system in which the company intends to invest [4]. The execution involved a thorough analysis of every stage of deploying the hybrid model, offering insights into both its benefits and drawbacks. Through this illustrative approach, the potential for employing the integrated method as a strategic tool in tackling complex software service selection issues was demonstrated. This not only enhances the company's decision-making visibility but also facilitates a clearer understanding of the evaluation process [4].

Initially, it is advisable to prioritize a limited number of suppliers, or potentially rely solely on a single supplier, to establish substantial partnerships. Concerning the implementation format of JIT procurement, the company necessitates a transitional period to shift from its existing multi-supplier network to constructing an efficient single-sourcing supplier network. Despite ongoing collaboration between companies and enhancements in delivery efficiency, the inherent risks of delayed shipments may introduce additional complexities to the production line. Consequently, one’s recommended an initial selection of two suppliers: one as the primary supplier and the other as a standby or backup. The purpose of this model is to quickly lower the risks and managing a Club sounds small business practice needs exchange of information, trust, and joint work of the participants and stakeholders [1].

The hybrid approach proposed by Yeh and Chang [15] utilizes a modeling policy solution with reduced attraction forces, thereby addressing computational complexity and enhancing its practical applicability. Unlike existing literature, this method is characterized as contemporary. Firstly, it outlines steps for determining criteria weights through an AHP. Additionally, it integrates Fuzzy Set Theory (FST) principles to further refine its performance [4]. This approach streamlines the computational complexity of operations by employing fuzzy-AHP with ease. While FST and AHP are commonly used methods, this application represents a notable achievement. Notably, the comprehensive integration proposed in this study has not

been previously addressed in similar service selection processes. Within this model, criteria for selecting software suppliers are clearly defined, and the underlying problem is meticulously outlined. This was achieved through a thorough comparison of ISO/IEC principles, relevant IT literature on software and suppliers, and the business drivers specific to the company [4].

Drawing from past research experiences, it is hypothesized that this study represents a pioneering endeavor, albeit with limitations regarding the relatively brief duration of participant interviews and the completion of questionnaires due to budgetary constraints and time limitations. Consequently, it is posited that a larger sample size of participants and respondents would enhance the persuasiveness of the study's findings [1].

In addition to the benefits of the proposed global supplier selection methods, this research can contribute by identifying additional supplier alternatives that encompass both domestic and international suppliers. However, it is important to acknowledge that such an expansion may introduce computational complexities [6].

In addition to addressing the multi-objective aspect of global supplier selection and the allocation of orders among chosen suppliers, it is imperative to also consider the complexities inherent in supplier selection problems. Typically, supplier selection is contingent upon time and demand considerations, and it may fluctuate over a given period. Therefore, it is essential to prioritize decision-making flexibility in such scenarios [6]. The article has potential for further development by encompassing factors such as supply capacity constraints and limitations in total quality and service aspects from the perspective of buyers in the supplier selection process. Additionally, the scope of global manufacturer selection could be broadened to incorporate considerations of environmental and ethical guidelines adhered to by manufacturing firms [6]. It is evident that suppliers should perceive the implemented decision-making framework and decision tree to evaluate the strengths and weaknesses of their operations. This assessment can guide them in adopting suitable strategies and implementing necessary changes to enhance the competitiveness of their products and the overall satisfaction of their customers. Consequently, ongoing support and maintenance, recognized as a crucial aspect, should be designated as a process subject to monitoring and improvement [4].

5 | Scope of the Future Work

Currently, industries utilize ERP software such as SAP for vendor performance evaluation, which serves as the foundation for outsourcing decisions. SAP includes performance rating scales, and feedback from the Quality Audit system is integrated into SAP. However, Quality Audits can only be conducted on existing vendors within an industry. When new vendors approach a business, there is no available performance data for these potential vendors. Only some subjective data is accessible, which is insufficient for making accurate decisions. The discussed method provides a suitable tool for ranking new vendor alternatives for outsourcing. Existing methods fail to consider all critical vendor attributes, such as the Buyer-Supplier Relationship and specific attributes for foreign vendors. The proposed model can encompass the maximum number of vendor performance attributes and can be tailored to particular industries. Future work may also involve validating this methodology using additional industry examples.

Acknowledgements

This is to certify that the research entitled “A Decision-Making Method for Supplier Selection in Industrial Manufacturing Industry: A Mathematical Framework of Integrating Analytical Hierarchical Process and Reliability Risk Evaluation” has been carried out by Chandan Chandra Sheel Department of Industrial Management, University of Vaasa, Vaasa, Finland; S M Atikur Rahman, Department of Industrial Manufacturing and Systems Engineering, University of Texas at EL Paso, USA; Tarapada Bhowmick, Department of Industrial Engineering, Khulna University of Engineering & Technology,Khulna,Bangladesh. The above research work or any part of the work has not been submitted anywhere for the award of any degree or diploma.

Author Contributions

The authors also would like to convey their gratitude and respect to the honorable Professor Dr. Tarapada Bhowmick,Department of Industrial Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh and S M Atikur Rahman, Department of Industrial Manufacturing and Systems Engineering, University of Texas at EL Paso, USA whose active guidance throughput the working period enable the authors to complete the project successfully. Without their proper and sincere support this work would not have been taken into shape.The authors would also like to thank Altex Fabrics Ltd, Beximco padma textiles, Amex knitting and dying Ltd, Artistic collectionand Dhaka to provide their earnest coordination in preparing this report efficiently.The main writer is myself write the full manuscript and edited this paper as instructed by the honorable editor of International Journal of Research in Industrial Engineering and with the guidance of honorable Professor Dr. Tarapada Bhowmick who helped me selection of topics and manufacturing industry and S M Atikur Rahman contributed in contextual development.Finally, the authors would also like to thank their friends, who helped them a lot through sharing the knowledge on the thesis topic.The authors lastly wish to pay tribute to their beloved parents for their support and tolerance in many ways to the project.

Funding

No external funding.

Data Availability

Data has been taken by interviewing with suppliers of the last six months of data prespective.

Conflicts of Interest

No conflict of interest.

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